

## MOVEMENTS OF LARVÆ OF THE ORIENTAL BEETLE THROUGH SOIL

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The movements of the larvæ of the oriental beetle (*Anomala orientalis* Waterhouse) in the soil were studied in Nassau County, N. Y., during the seasons of 1927 to 1933, inclusive. This paper deals with both the vertical and horizontal movements of the larvæ and some of the biological and environmental influences which affect these movements.

In order to secure some preliminary data in regard to movements of the oriental beetle larvæ in the soil, glass-sided cages<sup>2</sup> (17 inches long, 11 inches high, and  $\frac{3}{4}$  inch wide, inside dimensions) were constructed. Ten of these cages, which had been filled with compacted, sifted soil, were kept side by side in a box so that they were always in darkness except when the larvæ were being observed. Throughout the experiment they were kept in the laboratory at a temperature of approximately 70° F. Five of the cages contained growing wheat as food for the larvæ while the soil in the others was allowed to remain fallow. Ten third-instar larvæ, one having been placed in each of the cages, were observed and their positions in the soil charted three times daily for a period of three months. During this time the average distance moved by the larvæ in the fallow-soil cages was 32.9 feet, as compared with 13.9 feet for the larvæ in the cages with the growing wheat. The greatest recorded distance moved by a larva in the fallow soil was 47 feet and in a cage with growing wheat, 19.4 feet.

<sup>1</sup> The work reported in this paper was conducted under the general supervision of I. M. Hawley. The writer desires also to acknowledge the assistance of W. C. Phelon, F. W. Fletcher, C. E. Jennings, T. N. Dobbins, and C. R. Jones, who were formerly connected with the sublaboratory at Westbury, on Long Island.

<sup>2</sup> The glass-sided cages were designed and first used by W. E. Fleming in the study of larvæ of the Japanese beetle.

Observations on the movements of these larvæ have shown that they do not move in the same direction for any great length of time. The movements within a single day were generally both vertical and horizontal, and a larva often doubled back on its general course several times. The five larvæ in the cages containing food matured to adult beetles, but the development of the larvæ in the fallow cages was considerably retarded and two failed to mature.

#### VERTICAL MOVEMENT OF LARVÆ

Nearly all the data on vertical movements of larvæ in the soil have been obtained from the regular larval surveys made at Jericho, N. Y., during the seasons of 1927 to 1933, inclusive. Approximately 10 holes (12 inches square by 12 inches deep) were dug in sod land each week during the season when oriental beetle larvæ were active and the numbers of larvæ found at each inch in depth were recorded. The total number of larvæ recorded ranged from 3,000 to nearly 8,000 per season.

The curves in Figure 1 show the proportions of the total number of larvæ found at specified depths at 10-day intervals and thus indicate the vertical movements of the larvæ in the soil in 1928, a representative year, when 5,300 individuals in the immature stages were recorded in the diggings during the season. The dark areas in the lower part of Figure 1 represent the occurrence of the stages of the oriental beetle.

The most noticeable vertical movement of the larvæ is their seasonal downward movement in the fall for hibernation and their return in the spring to a position near the surface. This downward movement generally starts in October, when the mean soil temperature at the 3-inch level has fallen to approximately 50° F., and continues during November (Fig. 1). It has been observed during the past six winters that the larvæ pass the winter at depths ranging from 8 to 17 inches and that the greatest number are found around the 12-inch level. In the latitude of New York City the entire winter is generally passed in a quiescent condition, but occasionally during an exceptionally warm period in the winter months a slight upward movement has been observed. In January, 1932, there were three weeks of

warm weather when the mean soil temperature at the 3-inch level was 43° F. and a maximum temperature as high as 48.5° was reached. There were 4 days during this period when the mean soil temperature was approximately 45° F. Larval activity was

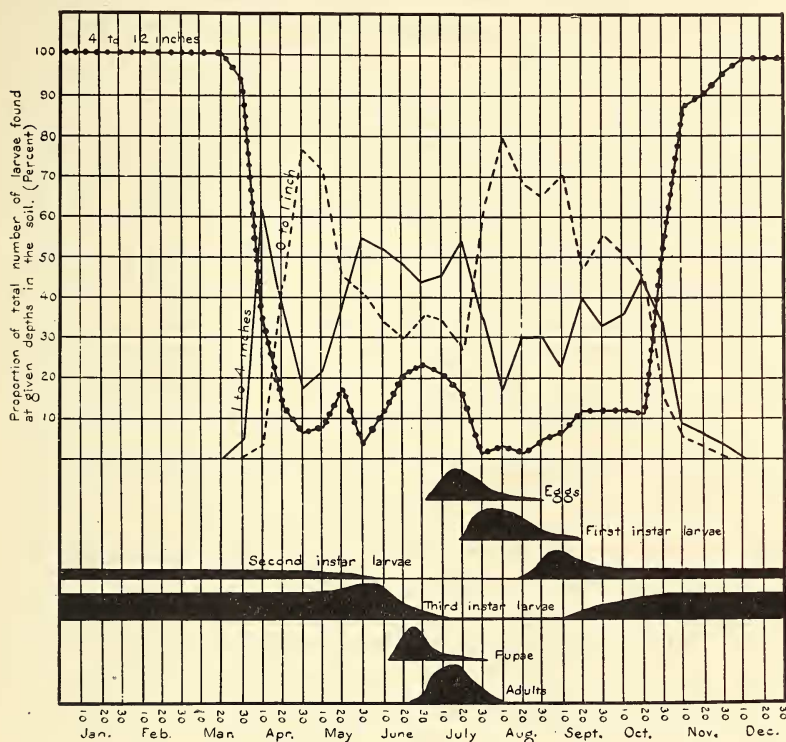


Figure 1.—Upper part: Vertical movement of oriental beetle larvæ in the soil, as indicated by the percentages of the total found at specified depths at 10-day intervals during the year 1928. Depth of larvæ in the soil: 0 to 1 inch, broken line; 1 to 4 inches, solid line; 4 to 12 inches, dotted line.

Lower part: Seasonal distribution of the different instars of the oriental beetle as they occurred in the field.

resumed and as a result larvæ moved upward to a position 4 to 6 inches below the surface, and a few even reached the second inch before the return of colder weather stopped this movement.

Normally, when the soil temperature at the 3-inch level has reached a mean of about 43° F. during the last part of March or first part of April, the larvæ start to move toward the upper layers of soil, but they do not reach their feeding position just beneath the surface in any numbers until the mean 3-inch soil temperature has become approximately 50° F. This is usually about the middle of April.

There is also a less pronounced vertical shifting of position throughout the time that larvæ are normally active. As will be explained later, this movement is due in part to changes in the soil moisture. A few oriental beetle larvæ can be found as much as 7 to 12 inches beneath the surface of the ground even during the real warm part of the year, but at that time the percentage of the larvæ occurring at any given depth decreases with the increase in depth in the ground (Fig. 1).

The female beetles oviposit in the ground at depths ranging from 1 to 11 inches. Most of the eggs are found at depths of 2 to 6 inches. Data secured during the season of 1932 as to the position in the soil of 1,590 eggs showed that 42 per cent were located in the soil below 4 inches. The young larvæ that hatch at these lower depths soon migrate upward to a position near the surface of the ground, where they feed on organic matter and the roots of plants.

When the larvæ have nearly completed their development in each of the three larval instars they generally move somewhat deeper into the ground before transforming to the next stage. This downward movement is more noticeable just before pupation than at the time of either of the two earlier larval molts (Fig. 1). The depth in the ground of 504 prepupæ and pupæ was noted while making surveys, and the percentages occurring at the various depths by inches were as follows: first, 0; second, 3; third, 4; fourth, 17; fifth, 20; sixth, 26; seventh, 14; eighth, 9; ninth, 3; tenth, 1; and eleventh inch less than 1 per cent.

Observations during the past seven years have shown that from 5 to 15 per cent of the oriental beetle larvæ fail to complete their development the first year. These fully developed larvæ move down to depths of 8 to 14 inches in the soil, where they remain until June of the following year before transforming to pupæ.

Surveys made in a cultivated garden at Jericho, N. Y., seem to show that the oriental beetle larvæ feed at greater depths in cultivated areas than in sod land. The diggings made in this garden in 1931 and 1932 showed 742 larvæ present in the area examined, and the percentage of the total found at the various depths were as follows: first inch 31, second to fourth inches 44, and fifth to tenth inches 25. Diggings were also made in a part of this garden where the ground was covered with a mulch consisting of straw and weeds. This cover caused the ground to remain moist beneath the mulch, and it was observed that as a result the larvæ were closer to the surface. Some of the larvæ were even on the surface of the ground just beneath the mulch. Where this mulch was present, 65 per cent of the larvæ were in the first inch of soil, 32 per cent in the second to fourth inches, and 3 per cent in the fifth to seventh inches. It would appear, therefore, that the moist soil condition near the surface under the mulch tended to cause the larvæ to move upward in the ground to a position similar to that found in the more moist situations, such as usually occur beneath grass sod.

This vertical movement in the soil must be considered when control measures are applied. Soil fumigations have often failed to kill 100 per cent of the larvæ when care has not been taken to reach the larvæ which have migrated temporarily to the lower depths. Chemicals, such as lead arsenate, are very effective, as they remain in the soil and kill the larvæ when they return and feed in the surface layer where the chemical is present.

#### HORIZONTAL MOVEMENT OF LARVÆ

The study of the horizontal movement of oriental beetle larvæ has been conducted primarily in cages, but some information has been obtained from field observations. Three types of cages were used in this study during the seasons of 1927 to 1933, inclusive. These consisted of a small movable cage and two types of larger field cages.

#### SMALL-CAGE EXPERIMENTS

The small cages were useful in studying the movements of the larvæ during short periods of time. The inside dimensions were 12 inches wide, 10 inches deep, and approximately 42

inches long. The sides of the cages were constructed of wood, the bottom of 2 layers of wire screen (6 and 18 mesh), and the top of 18-mesh wire screen (Figs. 2 and 3). This cover allowed the free passage of moisture but prevented oriental beetles from entering and ovipositing. Eight inches of sifted soil were placed in the cages and compacted. In order that the soil moisture might be as nearly as possible in a natural condition, the cages were sunk in the ground to such a depth that the soil within the cage was at the same level as that outside (Fig. 3). Wheat was grown in some of the cages and the soil in others was kept fallow. Within 2 inches of one end of each cage 100 oriental beetle larvæ were placed at a depth of about 2 inches. The experiments in the small cages were carried on during the late summer and fall months, when the larvæ were feeding actively, in the years 1927 to 1932, inclusive.

When the data from these tests were compiled it was found that the larvæ had moved slightly farther when the ground was fallow

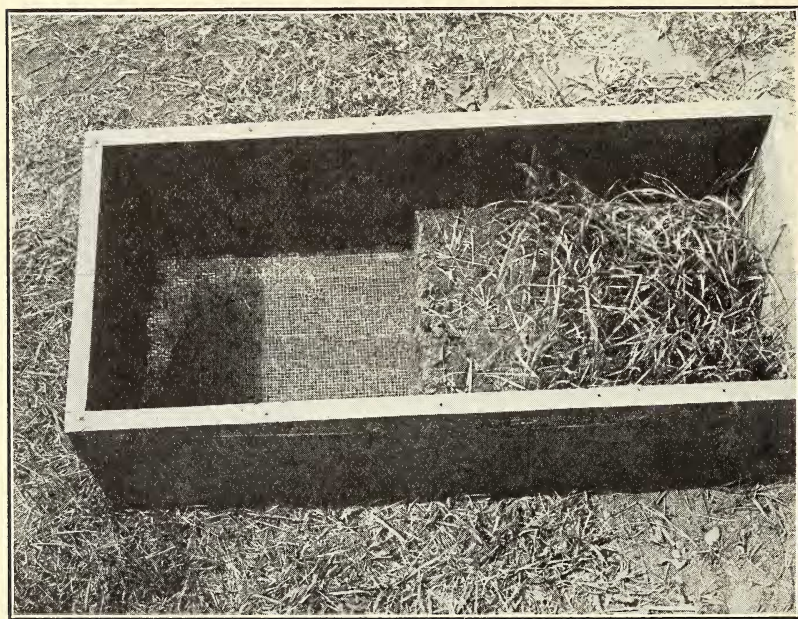


Figure 2.—Small migration cage, showing part of soil removed.

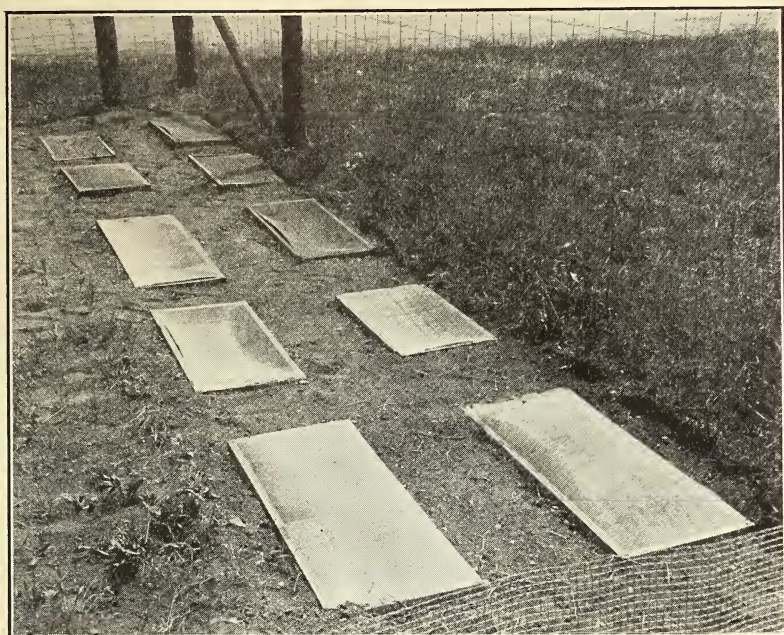


Figure 3.—A group of small migration cages.

TABLE 1  
HORIZONTAL MOVEMENT OF ORIENTAL BEETLE LARVÆ IN SMALL CAGES

Length of test in days	Total number of grubs recov- ered	Condition of cage	Proportion of larvæ, given in per cent, recovered at specified distances in inches from starting point						Greatest from starting point distance  Inches
			0-2	2-5	5-10	10-20	20-30	30-40	
1-2	275	fallow	32	24	17	14	7	5	35
3-5	167	fallow	24	20	18	15	12	11	35
3-5	351	wheat	22	20	22	24	7	2	34
7-10	319	fallow	8	17	18	32	16	9	40
7-10	253	wheat	19	28	24	17	10	0	33
14	236	fallow	5	9	12	43	24	7	34
14	117	wheat	5	26	33	23	10	1	33
21	154	wheat	24	25	27	19	3	0	24

than with wheat present, but that the total distance traversed was not great under either condition. The data on horizontal movement of larvæ in small cages are summarized in table 1.

#### EXPERIMENTS IN LARGE FIELD CAGES

The experiments with large field cages were started in 1932 and continued during 1933. The first of these tests was conducted in a cage 4 feet wide and 24 feet long. The sides of this cage were constructed of wood and were sunk in the ground to a depth of 11 inches. The cage did not have a bottom, and the top was covered with 18-mesh wire screening to exclude all oriental beetles. The soil in the cage was fumigated with 6 pounds of carbon disulphide to 100 square feet, as recommended by Fleming and Baker,<sup>3</sup> in order to destroy any larvæ which might be present in the soil, and was kept in a fallow condition throughout the test. A trench about 4 inches deep was dug across the center of the cage at a position 12 feet from each end. Three hundred third-instar larvæ were placed in this trench and covered with soil. This experiment was started during the last week of May. When the experiment was closed on June 28, one larva was recovered 25 inches from the center of the cage, but the remaining larvæ had moved much shorter distances. The distribution of the 232 larvæ surviving at the close of the experiment was as follows: 14 per cent were in the original central 2-inch strip, 50 per cent had moved from the center of the cage 1 to 5 inches, 25 per cent had travelled from 5 to 10 inches, and only 1 per cent was found between 20 and 25 inches from the starting point.

During the summer of 1932 two cages, each 24 feet square, were built. The sides of these cages were constructed of wood and were sunk in the ground 11 inches. The cages were without bottoms, but the top of each cage was covered with cheesecloth during the beetle season. The top of one cage was elevated 24 inches above the ground and the side portions were also covered with cheesecloth, thus allowing for the growth of plant material as food (Fig. 4). The soil in the cages was fumigated with

<sup>3</sup> Fleming, W. E., and Baker, F. E. Treatment of soil to destroy the Japanese beetle. *Jour. Econ. Ent.* 23: 502-508. 1930.

carbon disulphide by using the material as described in the previous field-cage experiment. Wheat was sown in the cage with the elevated top, and the soil in the other was allowed to remain fallow. Three hundred oriental beetle larvæ were placed in the center of each of the cages early in September 1932. In each cage the larvæ were evenly distributed over a central area with a radius of 18 inches.

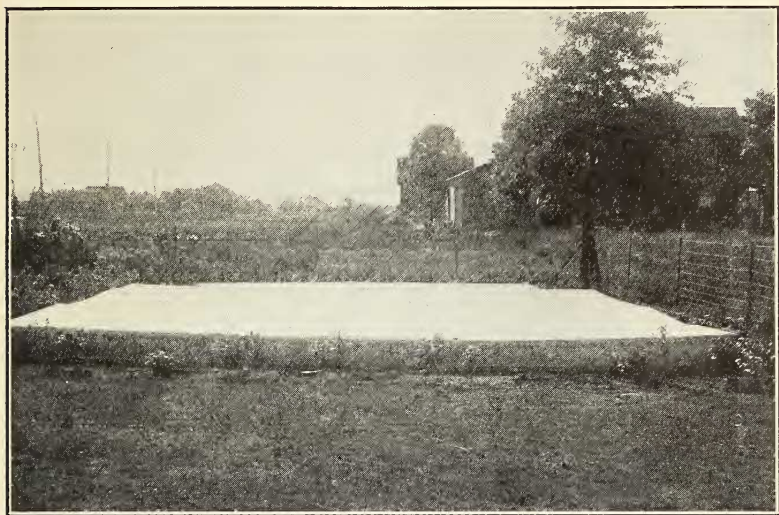


Figure 4.—Field migration cages.

The cages were examined in 1933, and the position of each of the 100 larvæ surviving in the wheat cage and the 174 larvæ surviving in the fallow cage was recorded. One fourth of each cage was examined during the first part of April 1933 before the spring migration started. The remaining three fourths were examined about June 15, after the horizontal movement of both fall and spring had taken place. The data obtained in this test are summarized in table 2.

There was but little difference in grub movement in the two cages. The larvæ included in the first column (0–18 inches) did not move beyond the starting area. There was no evidence of a greater movement in the fallow cages as was noted in tests

TABLE 2

HORIZONTAL MOVEMENT OF ORIENTAL BEETLE LARVÆ IN LARGE FIELD CAGES

Period of movement	Condition of cage	Proportion of larvæ, given in per cent, recovered between various distances in inches from center of cage					Greatest distance from center
		0-18	18-30	30-40	40-50	50-66	Inches
Fall	fallow	29	60	8	2	0	49
Fall	wheat	35	30	27	5	2	52
Fall and spring	fallow	14	33	23	28	1	57
Fall and spring	wheat	14	30	37	12	7	66

with small cages. Under the conditions of the experiment, some larvæ moved approximately 4 feet between September and June. It should be noted that though the fallow cage was kept free of grass and weeds, there was sufficient decomposed plant material present to furnish food for the larvæ, and as a result they were apparently not stimulated to move about as much as they were in the sifted soil in the small cages.

## FIELD OBSERVATIONS ON HORIZONTAL MOVEMENT OF LARVÆ

During the years of 1930 to 1932, inclusive, there was an infestation of larvæ of the oriental beetle in a strawberry bed at Jericho, N. Y., which increased in intensity each year, until by 1932 at least 80 per cent of the strawberry plants in this bed had been killed. Each year the destruction of the strawberry plants in a gradually enlarging area, as the larval season advanced, showed that some horizontal movement of larvæ had occurred. As a result of this severe injury to the plants, the strawberry bed was plowed up in September 1932 and the ground left fallow during the fall. After the strawberry plants had been killed, the migration into an adjoining red raspberry bed was very noticeable. No injury to the roots of the raspberry bushes was observed until after the strawberry plants had been destroyed and the bed plowed up. In fact, diggings made in the red raspberry bed during 1931 and 1932 disclosed almost no larvæ present at the time that the adjoining strawberry bed was heavily populated. Late in the fall of 1932 and during the

spring of 1933 a gradually increasing arc of dying red raspberry bushes appeared on the side of the bed which had been adjacent to the strawberry bed. The area of destroyed bushes increased until it extended inward as far as 10 feet in some places. The larval migration was so pronounced that approximately one-fifth of the raspberry bushes in this bed, 20 feet by 250 feet, were killed by the feeding of oriental beetle larvæ, and as many as 50 larvæ were present around the roots of a single bush.

Although the roots of lawn grasses are attacked by the oriental beetle larvæ more often than those of any other plant, it is extremely difficult to judge the amount of the horizontal movement of larvæ in lawns. The injured areas in lawns which have appeared in the late summer or fall during recent years range in size from a few square inches to 3 or 4 acres. In most cases, especially in the smaller areas, the larvæ tend to be more numerous in the living grass at the edge of the killed sod than they

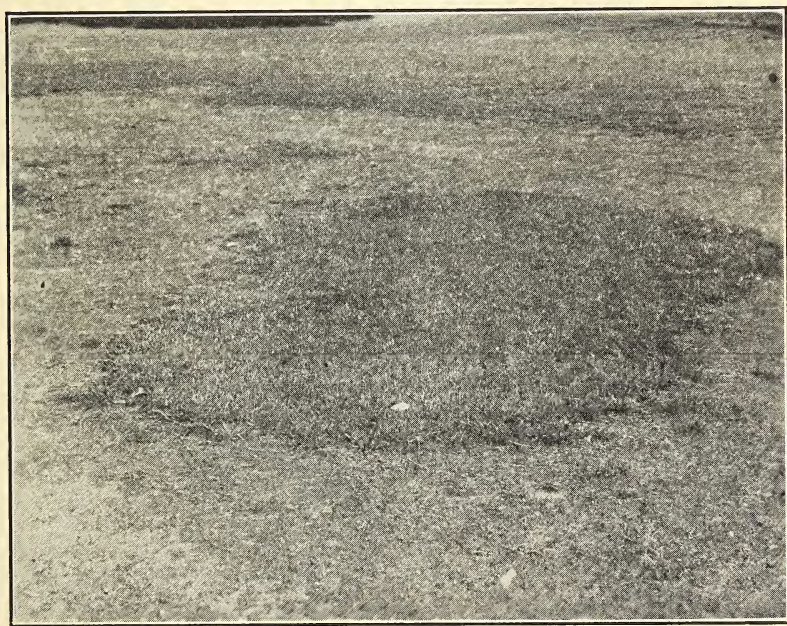


Figure 5.—Grass in central area growing on ground treated with 15 pounds lead arsenate per 1,000 square feet. The turf around this area was untreated.

are in the areas where the grass has already been killed by larval feeding. As was found to be the case in cage tests, the extent of the movement from the injured area is apparently governed by the amount of organic matter present and available as food.

When chemicals are applied to turf for the control of larvæ, it is important to keep in mind that areas surrounding the spots where plants have been killed are generally heavily infested, as the larvæ tend to move from such areas because of a scarcity of food. There have been several instances where gardeners have overlooked this migration and have treated only those parts or patches of a lawn where the turf has been killed. In these cases the application of lead arsenate at the rate recommended by the United States Department of Agriculture<sup>4</sup> killed the larvæ remaining in the treated area, but most of the larvæ that brought about the destruction of the turf were already feeding on more succulent food several feet away. By the following year it was evident that lawn protection had been secured in the treated patches, but grass was often extensively injured around these small treated areas (Fig. 5).

#### SUMMARY AND CONCLUSION

Larvæ of the oriental beetle have been found to move downward in the soil to depths of from 8 to 17 inches when the soil temperature at the 3-inch level has reached 50° F. In the spring after hibernation the return upward starts at a soil temperature of about 43° F. and is completed at 50° F.

Oviposition by the oriental beetle takes place at depths of 1 to 11 inches. Larvæ temporarily move deeper in the soil just before changing from one instar to the following instar or stage. Larvæ are usually found deeper in cultivated ground than in grass sod. This is often due to a smaller amount of soil moisture at the surface in the former situations.

There is good evidence that larvæ move horizontally in the soil. In large field cages some larvæ moved approximately 4 feet, and there was little difference in the extent of the movement as influenced by the presence or absence of wheat as food.

<sup>4</sup> Fleming, W. E., and Osburn, M. R. Control of larvæ of the Japanese and the Asiatic beetles in lawns and golf courses. U. S. Dept. Agr. Cir. 238, 10 pp., illus. 1932.

Field observations indicate that larvæ feed on the roots of plants until they are killed and then move on to other plants. The extent of the outward movement depends to some extent on the decomposed material in the soil that is available as food.

Where the fact of larval movement in the soil has been overlooked when insecticides were applied, there has been failure to protect turf from the oriental beetle larvæ.